



Study Quenching Process on Rubber Tapping Knives Home Production

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Abstract: The rubber tapping knives were often produced by blacksmiths experience cracks and chips or even break on the blade, so rubber farmers must frequently replace them with new knives. Thus, the product cannot be used for a long time, and its economic value is reduced. The reason why the rubber tapping knives made by blacksmiths are easily damaged is because the plating method on the product is not carried out correctly. So that the resulting product has a relatively low level of hardness. This study aims to determine the effect of the hardening and quenching processes on the hardness of rubber tapping knives made by blacksmiths. The test data were analyzed using ANOVA with a full factorial level design, a main effect model design, and 3 replications assisted by Design-Expert software. At a temperature of 800°C the maximum hardness value of 62.8 HRC was obtained from the quenching results using water cooling media, while the minimum hardness value of 62.2 HRC was obtained from oil cooling media. At a temperature of 850°C, the maximum hardness value of 60.4 HRC was obtained from quenching using water cooling media, and the minimum hardness value was obtained from oil cooling media of 59.1 HRC.

Keywords: Knives, Leaf Spring, Hardening, Quenching, ANOVA, Full Factorial

1. Introduction

Rubber remains one of Indonesia's leading plantation commodities, and its rubber plantations are the second largest in the world [1]. Several regions in Indonesia have suitable soil conditions for rubber cultivation, primarily in Sumatra and Kalimantan [2]. According to Khairinnisa Siregar, the area of rubber plantations in Indonesia in 2015 reached over 3.6 million hectares, spread across Indonesia: Sumatra (2.5 million hectares), Java (142,000 hectares), Nusa Tenggara and Bali (511,000 hectares), Kalimantan (905,000 hectares), Sulawesi (13,000 hectares), and Maluku and Papua (4.8,000 hectares) [3]. To harvest rubber latex, farmers tap or artificially wound the bark of rubber trees using a rubber tapping knife. The knife has a distinctive shape and is used exclusively for tapping rubber plants [4]. This knife is manufactured by a blacksmith using medium-carbon steel from discarded leaf spring components. Medium-carbon steel is steel with a carbon content between 0.25% and 0.60% C. This medium-carbon steel is widely

used for machine tools and can also be used for various purposes, such as in the automotive industry, gears, leaf springs, and so on [5]. The knives produced by the blacksmith often develop cracks, chips, or even breaks at the blade, forcing rubber farmers to frequently replace them. This results in a product that is less usable and has reduced economic value. It is suspected that the reason why the blacksmith's tapping knives are easily damaged is because the heat treatment method used on the products has not been carried out properly. One of the heat treatment processes for steel is hardening, better known as gilding. Rubber tapping knives are heated to a temperature at or above the critical temperature, followed by rapid cooling, a process called quenching. Quenching is the rapid cooling of steel after undergoing a heat treatment [6]. Quenching accelerates the cooling process from the final temperature, transforming austenite into ferrite and martensite, resulting in high strength and hardness [7]. As is known, the viscosity and

density of the cooling medium significantly influence the hardness. Viscosity is the degree of viscosity of a fluid. The higher the viscosity, the slower the cooling rate. Density is the density of the cooling medium (fluid). The higher the density of a cooling medium, the faster the cooling rate [7].

The following are the viscosity and density values of the cooling media used: Salt Water ($\rho = 1025 \text{ kg/m}^3$, $\nu = 1.01 \text{ Pa.s}$) Salt water has a low viscosity, resulting in a fast-cooling rate. Its density is also higher than other cooling media such as water, diesel, oil, and air. Water ($\rho = 998 \text{ kg/m}^3$, $\nu = 1.01 \text{ Pa.s}$). Water (H₂O) is the most used cooling medium due to its low cost. Water has a high density but is lower than salt water, and its viscosity is low, like that of salt water, but its cooling rate is slower than that of salt water. Oil ($\rho = 981 \text{ kg/m}^3$, $\nu = 4.02 \text{ Pa.s}$) [7]. Oil is a hydrocarbon compound (C₈H₁₈) that has a higher viscosity than other cooling media and a low density, resulting in a slow cooling rate [8]. Air ($\rho = 1.2 \text{ kg/m}^3$, $\nu = 0.00001.75 \text{ Pa.s}$). Air has a very low density and viscosity, resulting in a very slow cooling rate [9]. The purpose of quenching is to increase metal hardness, while the primary factor in the quenching process is controlling the cooling rate [10]. If the cooling rate is too slow, the metal becomes more brittle and its hardness decreases. If the cooling rate is too fast, distortion and cracking will occur in the metal [11]. Hardening is a process that changes the structure of a metal by heating the workpiece in a furnace at a specified temperature for a specific period and then rapidly cooling it with a cooling medium such as water, brine, oil, and diesel fuel, each of which has a different cooling density. Heat hardening treatment is a combination of heating and cooling of a metal or alloy in the solid state to obtain specific properties [12]. According to Setiawan *et. al.*, the hardening process for hardness testing involves a combination of treating truck spring steel, a temperature of 850°C, a holding time of 10 minutes, and a cooling medium of banana sap to achieve the highest hardness value of HRC 63.03[2]. Based on the Taguchi method analysis, the four factors that most influence material hardness are temperature, holding time, cooling medium, and the least significant is the material. The results of data analysis show that knives using water cooling media have an average hardness value of 652.64 HV, knives using salt water cooling media have an average hardness value of 836.56 HV, knives using oil cooling media have an average hardness value of 600 HV and knives using air cooling media have an average hardness value of 335.44 HV [13]. From the data analysis, it was concluded that the knife manufacturing process using oil cooling media is the best because it produces knives with a high level of hardness accompanied by a good level of ductility so that they are not brittle. Based on testing, specimens that have not undergone treatment have a low hardness value (HRC) of 38.38, while specimens that have received heat treatment and cooled with seawater have a higher hardness value (HRC) of 61.02. 2 [5]. This is because every carbon steel that undergoes heat treatment will have its hardness value increased. Abdul Choliq, DN Paundra F *et. al.* (2024), test results showed that

the hardness of experimental knife A in the blade area reached 730 HV with a martensite and chromium carbide microstructure, and in the blunt area the hardness decreased to 313 HV with a martensite and retained austenite structure. Meanwhile, experimental knife B, which was thoroughly hardened, achieved a hardness of 627 HV and a martensite microstructure with evenly distributed fine chromium carbides. The results of the knife-making experiment approached the mechanical properties of imported knife X, which has a tempered martensite matrix microstructure with carbides and a hardness level of 640 HV. Based on the research conducted above, this study aims to increase the hardness of rubber tapping knives made by blacksmiths through hardening and quenching heat treatments. This will result in a superior product as desired. This study aims to determine the effect of hardening and quenching heat treatments on rubber tapping knives, resulting in improved quality in terms of better surface hardness and longer product life.

The aims and benefits of this research are determining the effect of the hardening and quenching heat treatment processes on the hardness of rubber tapping knives and improving the quality of rubber tapping knives produced by blacksmiths to improve the well-being of blacksmiths and rubber farmers.

2. Methods

This study was designed using an experimental approach to quantitatively investigate the effect of varying doses of the wetting agent magnesium (Mg) on the hardness and microstructural characteristics of Aluminum Matrix Composites (AMCs) reinforced with silicon carbide (SiC) and rice husk ash (RHA). The materials used consisted of aluminum scrap as the matrix, SiC and RHA as the reinforcement phases, and magnesium (Mg) as the wetting agent. To isolate the effect of Mg, the weight fractions of SiC and RHA were kept constant at predetermined levels (e.g., 2% SiC and 2% RHA of the total matrix weight), while Mg was varied into three groups: 0 g (control), 1.0 g, and 1.5 g. All composite fabrication processes were carried out using the stir casting method.

Tools and materials were used in this study. 12 heat-treated test specimens, 3 non-heat-treated specimens, 3 raw materials, and 1 specimen for composition testing. Nabertherm™ Chamber Furnace N 321/13, clamping pliers for lifting specimens from the furnace, container for quenching media. SAE 40 oil quenching media, Rockwell hardness tester, Model HR 150 A, Vernier calipers, Hand grinder, sandpaper, file, steel wire for binding specimens.

The research steps were as follows:

1. Specimen preparation. The preparation process began with preparing the rubber tapping knife specimens to be tested. The specimens were measured using vernier calipers and then cut using a hand grinder. The test specimens were 50 mm long and 5 mm thick. The specimens for composition testing measured 40mm x 40mm and were 5mm thick. They

were then leveled using a file and sanded to achieve a flat and smooth surface.

2. **Hardening Process:** First, the specimens were prepared and inspected. They were then tied with steel wire to facilitate removal from the furnace and facilitate the cooling process. Once the specimens were prepared, they were placed in the furnace in an orderly fashion and arranged for easy removal. The furnace was set to reach temperatures of 800°C and 850°C, with a holding time of 30 minutes. The temperature was determined based on the carbon content and the Fe3C phase diagram.

3. **Quenching Process:** After holding for 30 minutes, the specimens were removed from the furnace using pliers and quickly immersed in a cooling medium of water and SAE 40 oil. After the specimens cooled, they were cleaned of any remaining dirt or oil.

4. **Hardness Testing:** Hardness testing was conducted to determine the differences between different temperatures and cooling media. Testing was conducted on both hardened and unhardened specimens. Hardness testing was performed at five points on the surface of each specimen. The standard used in this test is ASTM E18.

5. **Composition Testing:** Composition testing was conducted to determine the levels of Fe and C, as well as other elements, contained in the rubber tapping blade specimens. Testing was conducted at the Mineral Technology Research Center of the Indonesian Institute of Sciences in Tanjung Bintang, South Lampung. Composition testing was conducted using a Spark Optical Emission Spectrometer (OES). This tool can analyze the elemental composition of carbon steel, Al-base, Zn-base, and cast iron with relatively fast and accurate testing and precise results.

3. Result and Discussions

3.1. The Result of Composition Test

From the composition test results, it was determined that the test specimen was a medium carbon steel with a carbon (C) content of 0.544%.

This type of carbon steel can be hardened directly, allowing the hardening heat treatment process to be applied to the test specimen. The composition test results can be seen in Table 1 below.

Table 1. Result of Composition Test

Element	Medium Carbon Steel	
	(%)	Method
C	0.544	Spark – OES Spectromaxx
Si	0.238	Spark – OES Spectromaxx
Mn	0.820	Spark – OES Spectromaxx
P	0.0146	Spark – OES Spectromaxx
S	0.0030	Spark – OES Spectromaxx
Cr	0.754	Spark – OES Spectromaxx
Mo	0.0102	Spark – OES Spectromaxx
Ni	0.00665	Spark – OES Spectromaxx
Al	0.0390	Spark – OES Spectromaxx

Co	0.0095	Spark – OES Spectromaxx
Cu	0.0156	Spark – OES Spectromaxx
Ti	0.0142	Spark – OES Spectromaxx
Sn	0.0011	Spark – OES Spectromaxx
As	0.0022	Spark – OES Spectromaxx
Zr	0.0039	Spark – OES Spectromaxx
Ce	0.0036	Spark – OES Spectromaxx
Se	0.0022	Spark – OES Spectromaxx
Te	0.0047	Spark – OES Spectromaxx
Ta	0.0402	Spark – OES Spectromaxx
B	0.00021	Spark – OES Spectromaxx
Zn	0.0012	Spark – OES Spectromaxx
La	0.00053	Spark – OES Spectromaxx
Fe	97.4	Spark – OES Spectromaxx

The calculations and explanations in Table 5. are as follows:

A = Water Quenching Media Factor

B = Oil Quenching Media Factor

R1 = Hardness (Response 1)

Standard deviation of factor A

$$\sigma_a = \sqrt{\frac{\sum(X - \bar{X})^2}{n-1}} = 1.48155$$

Standard deviation of factor B

$$\sigma_b = \sqrt{\frac{\sum(X - \bar{X})^2}{n-1}} = 1.84029$$

After carrying out hardness testing using the Rockwell method, the following hardness test results were obtained in Table 2:

Table 2. Result of hardness test without heat treatment

Specimen	Test Point	Indenter	P		HRC
			(kg)	HRC	Average
	1	Diamond 120°	150	34.0	31.9
	2			34.9	
	3			35.0	
	4			25.5	
	5			30.0	
Without Heat treatment	1	Diamond 120°	150	27.0	31.4
	2			28.0	
	3			35.5	
	4			32.5	
	5			34.0	
	1	Diamond 120°	150	37.7	36.5
	2			38.0	
	3			37.5	
	4			37.0	
	5			32.5	
Total					33.2

Table 3. Result of hardness test blacksmith product

Specimen	Test Point	Indenter	P		HRC
			(kg)	HRC	Average
Blacksmith Product	1	Diamond 120°	150	28.0	28.9
	2			26.5	
	3			29.8	
	4			30.0	
	5			30.5	
	1	Diamond 120°	150	47.3	51.1
	2			55.5	
	3			50.6	
	4			51.5	
	5			50.5	
	1	Diamond 120°	150	48.5	43.3
	2			34.5	
	3			42.5	
	4			48.2	
	5			42.9	
Total					41.1

Table 4. Result of hardness test Water at Temperature 800°C

Specimen	Test Point	Indenter	P		HRC
			(kg)	HRC	Average
Media Quenching Water at Temperature 800°C	1	Diamond 120°	150	62.0	62.7
	2			63.0	
	3			64.4	
	4			63.6	
	5			60.4	
	1	Diamond 120°	150	63.0	63.3
	2			63.2	
	3			61.4	
	4			64.4	
	5			64.6	
	1	Diamond 120°	150	61.6	62.3
	2			63.3	
	3			62.5	
	4			63.0	
	5			61.4	

Table 4. Result of hardness test Water Quenching at Temperature

Specimen	Test Point	Indenter	P		HRC
			(kg)	HRC	Average
Media Quenching Oil at Temperature 800°C	800°C				
	1	Diamond 120°	150	61.0	62.3
	2			62.5	
	3			63.5	
	4			63.0	
	5			61.6	
	1	Diamond 120°	150	60.6	62.4
	2			62.4	
	3			61.5	
	4			63.0	
	5			63.2	
	1	Diamond 120°	150	61.5	61.9
	2			63.5	
	3			62.4	
	4			61.6	
5	60.6				
Total					62.2

Table 5. Result of hardness test media quenching water at temperature 850 °C

Specimen	Test Point	Indenter	P		HRC
			(kg)	HRC	Average
Media Quenching Water at Temperature 850°C	1	Diamond 120°	150	59.7	60.6
	2			58.8	
	3			61.6	
	4			59.5	
	5			63.5	
	1	Diamond 120°	150	57.0	61.6
	2			60.4	
	3			67.0	
	4			62.1	
	5			61.6	
	1	Diamond 120°	150	58.5	59.2
	2			59.7	
	3			58.8	
	4			59.5	
	5			59.6	
Total					60.4

Table 6. Result of hardness test media quenching oil at temperature 850 °C

Specimen	Test Point	Indenter	P (kg)	HRC	HRC Average
Media Quenching Oil at Temperature 850°C	1	Diamond 120°	150	55.6	57.8
	2			59.5	
	3			57.0	
	4			59.4	
	5			57.6	
	1	Diamond 120°	150	59.6	59.9
	2			59.5	
	3			60.0	
	4			60.5	
	5			59.7	
Total					59.1

The results of the hardness test data were obtained as shown in Table 4.2, the minimum, maximum, average, standard deviation and ratio values of each response and factor in the test were obtained, then made in the form of Tables 3 and 4.

Table 7. The average of Standard deviation, Ratio of Hardness result test

<i>Design Model : Main Effect</i>		
<i>Design Type : Full Factorial</i>		
<i>Runs : 6</i>		
	Factor	
<i>Name</i>	A	R1
<i>Units</i>	Water	Hardness
<i>Minimum</i>	°C	HRC
<i>Maximum</i>	800	59.2
<i>Mean</i>	850	63.3
<i>Std. Dev</i>		61.65
<i>Observation</i>		1.48155
<i>Analysis</i>		6
<i>Ratio</i>		factorial
		1.06926

Table 8. The average Standard deviation, Ratio of Hardness result test

<i>Design Model : Main Effect</i>		
<i>Design Type : Full Factorial</i>		
<i>Runs : 6</i>		
	Factor	
<i>Name</i>	B	R1
<i>Units</i>	Oil	Hardness
<i>Minimum</i>	°C	HRC
<i>Maximum</i>	800	57.8
<i>Mean</i>	850	62.4
<i>Std. Dev</i>		60.67
<i>Observation</i>		1.84029
<i>Analysis</i>		6
<i>Ratio</i>		factorial
		1.07958

Table 9. Analysis varians spesimen water quenching and quenching

<i>ANOVA for selected factorial model Analysis of variance table</i>						
<i>[Partial sum of squares - Type III]</i>						
Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	7.94	1	7.93	9.30	0.0381	Significant
Water Pure	7.94	1	7.94	9.30	0.0381	
Error	3.41	4	0.85			
Cor Total	11.35	5				

Table 10. Analysis varians spesimen Oil quenching and quenching

<i>ANOVA for selected factorial model Analysis of variance table</i>						
<i>[Partial sum of squares - Type III]</i>						
Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	14.11	1	14.11	19.96	0.0111	Significant
Oil Pure	14.11	1	14.11	19.96	0.0111	
Error	2.83	4	0.71			
Cor Total	16.93	5				

Based on the ANOVA results, $F_{count} (F_0) > F_{table}$, the hypothesis (H_0) is rejected. It can be concluded that the temperature variation and quenching media factors influence the hardness of the rubber tapping knife specimens with a 95% confidence level ($\alpha = 0.05$). The largest F_{count} value is found in the oil quenching media parameter, indicating that the main factor that most influences the hardness of the test specimen is the oil quenching media. The percentage contribution of each influencing factor can be calculated as follows:

$$\begin{aligned} \text{Water Factor} &= ((7.94-3.41))/(11.35) = 39\% \\ \text{Oil factor} &= ((14.11-2.83))/(16.93) = 42\% \end{aligned}$$

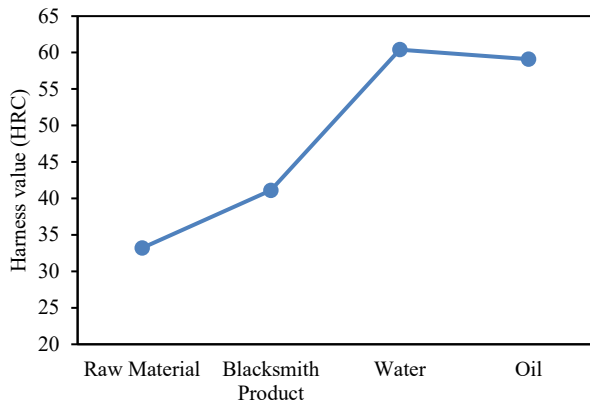


Figure 1. Hardness Test Result at Temperature 800°C

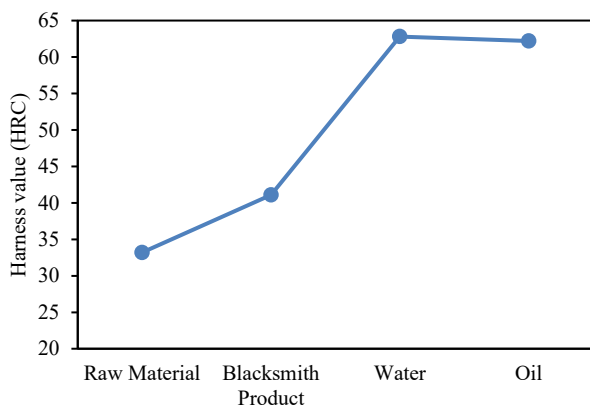


Figure 2. Hardness Test Result at Temperature 850°C

The graphs shown in Figures 1 and 2 show a significant increase in hardness between the test specimens after hardening and quenching. Differences in temperature and cooling medium affected the hardness of each test specimen. At 800°C, the maximum hardness value was 62.8 HRC, obtained from quenching using water, while the minimum hardness value was 62.2 HRC, obtained from oil. At 850°C, the maximum hardness value was 60.4 HRC, obtained from quenching using water, and the minimum hardness value was 59.1 HRC, obtained from oil.

The analysis of variance revealed that the variations in temperature and cooling medium significantly influenced the increase in hardness. The hardness test results showed differences in the hardness increase for each specimen. However, the percentage contribution calculation indicated that oil quenching had a greater effect on the hardness of the test specimens than water.

4. Conclusion

Based on the test results and data analysis can be concluded the composition test revealed that the leaf spring steel specimens used as raw materials for rubber tapping knives are medium carbon steel with 97.4% iron (Fe) and 0.544% carbon (C). The hardness test revealed an increase in

hardness in the rubber tapping knife specimens. At 800°C, the maximum hardness value was 62.8 HRC, obtained from quenching using water, while the minimum hardness value was 62.2 HRC, obtained from oil. At 850°C, the maximum hardness value was 60.4 HRC, obtained from quenching using water, and the minimum hardness value was 59.1 HRC, obtained from oil. Therefore, the appropriate temperature and cooling medium for achieving a high level of hardness is water cooling at 800°C. The analysis revealed that the factor most influencing the hardness level was the oil cooling medium, contributing to 42%, while the water-cooling medium contributed 39%. The carbon content in the oil compound (C8H18) allows the addition of carbon to the test specimen, thereby increasing its hardness. However, this does not apply to specimens cooled with water (H₂O). The difference in viscosity between the two-cooling media also affects the hardness level of the specimen. Water cooling media, with its fast-cooling rate, results in a high hardness level. Conversely, with oil cooling media, the cooling rate tends to be slower, resulting in lower hardness values for the test specimens than those cooled with water.

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